

# Enrichment planting in a logged-over tropical mixed deciduous forest of Laos

Sovu • Muluaem Tigabu • Patrice Savadogo • Per Christer Odén

Lamphoune Xayvongsa

Received: 2009-06-08; Accepted: 2009-08-01

© Northeast Forestry University and Springer-Verlag Berlin Heidelberg 2010

**Abstract:** Enrichment planting is commonly used for increasing the density of desired tree species in secondary forests often characterized by a prevalence of low commercial species. The objectives of the study were to identify the optimal enrichment planting method vis-à-vis gap and line planting, and to evaluate the performance of two dipterocarps (*Vatica cinerea* and *Dipterocarpus alatus*) and three legumes (*Azelia xylocarpa*, *Pterocarpus macrocarpus*, *Dalbergia cochinchinensis*) planted in logged-over mixed deciduous forest of Laos. The enrichment planting trial was arranged in a randomized complete block design with seven replications. Survival, height and diameter were measured seven years after planting and subjected to analysis of variance. Survival rate of planted seedlings did not vary between enrichment planting ( $p > 0.05$ ). However, diameter and height growth was favored more in gaps than in planting lines. This was related to rapid canopy closure in both gaps and lines, albeit more remarkable in planting lines. Significant inter-species variation was detected for survival rate, height and diameter. The shade-tolerant dipterocarps had better survival and growth than the light-demanding leguminous species ( $p < 0.0001$ ). The size class distribution of individuals was irregular, accentuating uneven light condition in the understory. Given the difficulty to maintain constant line width and even light condition, the cost of annual clean operation and the rigid geometric patterns of

planting lines, the use of logged-over gaps for enrichment planting is recommended. *Dipterocarpus alatus* and *V. cinerea* are recommended for enrichment planting in mixed deciduous forests. *A. xylocarpa*, *D. cochinchinensis* and *P. macrocarpus* can be planted in wider gaps, lines and open sites as plantation of mixed species or under canopy of young swidden forests.

**Keywords:** Gap planting; Line planting; Secondary forest; Species trial; Tropical forest

## Introduction

Over-exploitation and fragmentation of natural forests have been typical problems in Southeast Asia, though its intensity varies from one country to another. In Laos alone, the forest cover had declined from 17 million hectares in 1940 to 11 million hectares by 1993 (Domoto 1997). As in other developing countries, the existing forests are also degraded due to tree felling by shifting cultivators and timber poachers (Foppes 1995; Jacobs 1996). In many instances, the officially designated forests are actually scrub formations comprising of few trees, implying that the real forest area is smaller than the official estimates and/or heavily under-stocked with desirable species. Secondary succession on logged-over tropical deciduous forest is often characterized by a prevalence of low commercial value species. In recent years, there have been attempts to accelerate the recovery of degraded forest and deforested land, restore productivity and biodiversity and for climate mitigation. Enrichment planting is the preferred method of assisting the natural regeneration of degraded forests when desirable species are absent or are present at low densities (Apanah and Weinland 1993).

Enrichment planting is defined as the introduction of valuable species into degraded forests without eliminating valuable individuals already present (Lamprecht 1990). It has been suggested as a technique for restoration of overexploited and secondary forests in stands no longer offering the possibility of a harvest in

---

Foundation project: The data collection for the present study was financed by the Swedish International Development Cooperation Agency (Sida).

The online version is available at <http://www.springerlink.com>

---

Sovu • Muluaem Tigabu (✉) • Patrice Savadogo • Per Christer Odén  
Swedish University of Agricultural Sciences, Faculty of Forest Sciences,  
Southern Swedish Forest Research Centre, PO Box 101, SE-230 53  
Alnarp, Sweden. E-mail: [Muluaem.Tigabu@ess.slu.se](mailto:Muluaem.Tigabu@ess.slu.se);  
[sovu@seng@yahoo.com](mailto:sovu@seng@yahoo.com)

Lamphoune Xayvongsa  
National University of Laos, Faculty of Forestry, PO Box 7322  
Vientiane, Lao P.D.R. E-mail: [lamphounex@yahoo.com](mailto:lamphounex@yahoo.com)  
Responsible editor: Chai Ruihai

the mid-term, and where ecological restoration is an objective (Ådjers et al. 1995; Montagnini et al. 1997; Ashton et al. 2001; Paquette et al. 2006). It may be useful in areas where natural regeneration is insufficient, for reintroducing species that have disappeared following overexploitation or to establish forest species that are inappropriate in open plantations. It involves planting of species of commercial or high local values using different approaches such as line-, under- or gap-planting. Line planting consists of cutting lines or transects of a given width through the existing vegetation and planting seedlings of the desired species at regularly-spaced distance along these lines. The light level created by the line depends on the direction and width of lines, and on the height of the surrounding vegetation, which are species-specific (Ådjers et al. 1995; Montagnini et al. 1997; Peña-Carlos et al. 2002). Although line planting has been applied successfully in different places, it is not widely practiced due to high cost of regular maintenance of the lines and rigid geometric patterns, making the stand look less natural. Contrary to planting in regularly spaced lines, gap planting has better resemblance to natural gap dynamics (Denslow 1987), which could be considered advantageous in restoration programs.

Generally, canopy openness (Jennings et al. 1999) and quality of light (Leakey et al. 2003) appear to be key factors influencing the survival rates (Peña-Carlos et al. 2002) and growth of under-planted seedlings (Tuomela et al. 1996; Romell et al. 2008). For tropical rain forest species, partial shade has been shown to be the best growth environment, albeit inter-species differences in shade responses (Ashton 1995; Tennakoon et al. 2005). In addition to direct effects on light conditions at the forest floor, other factors such as soil moisture, nutrient availability, the occurrence of severe stresses and other potentially damaging agents may influence the survival and establishment of under-planted seedlings. However, the importance of these factors may change temporally as the surrounding vegetation recovers and the planted seedlings develop.

Current knowledge about factors affecting the results of enrichment planting and the performance of seedlings planted in logged-over mixed deciduous forests of Laos is limited. Most studies on enrichment planting in Southeast Asia focused mainly on dipterocarps (e.g. Ådjers et al. 1995; Tuomela et al. 1996; Marod et al. 2004; Romell et al. 2008). Such information is highly needed, as Laos is changing its forest management policies towards restoration of degraded forests and reforestation programs through enhanced local participation. As stipulated in the Forestry Strategy 2020 document (MAF 2005), it is envisaged to increase the national forest cover to 70% by the year 2020 through establishment of plantations and natural regeneration of degraded forests including fallow forests. Therefore, we examined the performance of five native tree species planted in degraded mixed deciduous forest in Laos after seven years. The main objectives of the study were to identify the optimal enrichment planting method vis-à-vis planting gaps and planting lines, and select species that are suitable for rehabilitating degraded mixed forests. We hypothesized that: (1) survival and growth of tree species will be higher in smaller gaps than on wider planting lines due to the direct and indirect effects of canopy openness, and (2) in-

ter-species variation may exist due to species-specific response to conditions created in gaps and planting lines.

## Materials and Methods

### Study area

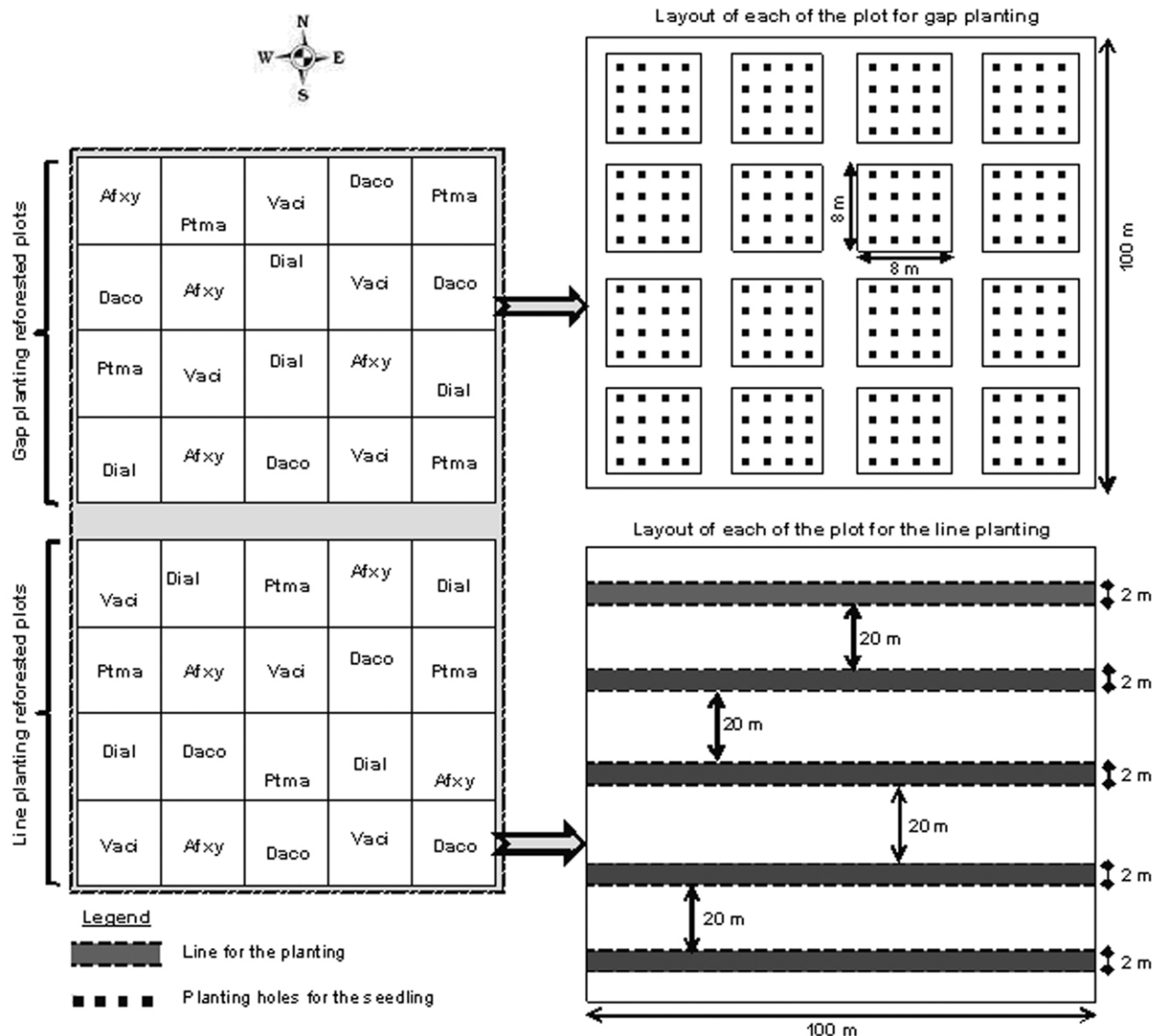
The study site is located at Napo and Nongboua villages in Sang Thong District, 70 km north-west of Vientiane, the capital of Lao Peoples Democratic Republic (18°16'26" N and 102°10'31" E). It is characterized by hilly topography with altitudes varying between 200 and 400 m a.s.l. and a typical monsoon climate with a distinct rainy and dry season. Based on data collected by the Department of Meteorology in Vientiane from 1995 to 2005, the mean monthly rainfall was about  $1647 \pm 16.4$  mm during the rainy season and mean daily temperature was  $26.74 \pm 0.66^\circ\text{C}$ . The geological formation consists mainly of sandstone, and alisol is the dominant soil type (MAF 1996). The prevailing forest type is a mixed deciduous forest, covering an area of 400 ha, with *Lagerstromia* sp., *Irvingia malayana* Oliver ex A. Benn., *Sandoricum koetjape* Merr., *Dipterocarpus costatus* C.F. Gaertn., *Hopea ferrea* Heim as the most common woody species (FOF/GTZ 1996). The majority of the forests were heavily degraded by logging activities during the last four decades by Japanese logging company, Osaka, which harvested rosewood, *Pterocarpus macrocarpus* Kurz and *Dalbergia* spp. for about three years and followed by the State Logging Company which operated in the area from 1981 to 1991 (Thapa 1998). The remaining mixed deciduous forest is now characterized by the rampant occurrence of bamboo in the understory and a low abundance of high-value commercial tree species, like *Azelia*, *Dalbergia* and *Pterocarpus* (Dietmar et al. 2001), in the upper-story. The stocking volume above 20 cm DBH in general does not exceed  $120 \text{ m}^3 \cdot \text{ha}^{-1}$  (PROFEP 2001).

### Experimental design

Enrichment planting plots were established in 2000 by the Faculty of Forestry, National University of Laos, with an area of approximately 40 ha of logged-over tropical mixed deciduous forest. The forest was divided equally into two blocks (20 ha each); one of which was used for gap planting and the other for line planting. Before the rainy season, planting lines and gaps were created by selectively cutting down the aboveground layer (non-commercial trees and shrubs) and clearing the ground layer. A total of 16 gaps were created per ha; each gap covered an area of  $8 \times 8$  m and the distance between two successive gaps was 20 m, measured from the gap center (Fig. 1). For line planting, five lines with 100 m length and 2 m width were set per hectare, separated by 20 m from each other (Fig. 1). The planting lines were oriented east to west to ensure the incidence of light. Within each block, seedlings of five indigenous tree species: *Azelia xylocarpa* Craib, *P. macrocarpus*, *Dalbergia cochinchinensis* Pierre, *Vatica cinerea* King and *Dipterocarpus alatus* Roxb were planted. The first three species belong to Fabaceae/Leguminosae while the last two species are members of the Dipterocarpaceae. Most dipterocarp species are

shade tolerant while the legumes exhibit a range of responses to light from intermediate to light-demanding (Table 1). The species represented in the present study are also highly appreciated for

their high quality timber and non-timber products such as oleo-resins and natural anti HIV constituents (Bräutigam 1996; Ankarfjard and Kegl 1998; Zhang et al. 2003).



**Fig. 1** Layout of the experimental design for enrichment planting of *Azela xylocarpa* (Afxy), *Pterocarpus macrocarpus* (Ptma), *Dalbergia cochinchinensis* (Daco), *Vatica cinerea* (Vaci) and *Dipterocarpus alatus* (Dial) in gaps and lines.

Seedlings were raised at the experimental nursery of the Faculty of Forestry, National University of Laos. In each gap, 16 nursery-raised seedlings were planted at  $2\text{m} \times 2\text{m}$  spacing, resulting in 256 seedlings per hectare. Each species was planted solely in a given gap. For line planting, 50 seedlings per line were planted at 2 m spacing, resulting in 250 seedlings per hectare. Cleaning of the lines and gaps were made twice at the beginning and once per annum afterwards for the first 5 years. In 2007, seven gaps and lines each (considered as replicates during data analysis) were randomly chosen for data collection for each species. During the inventory, all individuals in gaps and lines were counted, and their root collar diameter and height were measured.

#### Statistical analysis

Survival rate was computed for each species and planting method as the proportion of individuals encountered seven years after planting to the initial number of planted seedlings. The mean height and root collar diameter of all individuals per gap and line were computed and used for further statistical analyses. Prior to analysis of variance (ANOVA), the survival rate was arc-sine-transformed to meet the normality and homogeneity of variance assumptions (Zar 1996).

ANOVA was performed based on the following general linear

model:

$$Y_{ijk} = \mu + \beta_i + \lambda_j + (\beta\lambda)_{ij} + \varepsilon_{ijk} \quad (1)$$

where  $Y_{ijk}$  is the response variable (survival rate, diameter and height),  $\mu$  the overall mean,  $\beta_i$  the effect of enrichment planting method,  $\lambda_j$  the effect of species,  $(\beta\lambda)_{ij}$  the interaction effect, and  $\varepsilon_{ijk}$  is the random error with  $k$  number of replicates. Means that exhibited significant differences were compared using Tukey's test

at the 5% level of significance. To examine the population structure of planted seedlings after seven years, individuals from each planting method and species were grouped into five collar diameters ( $\leq 1.0$  cm, 1.0–1.9 cm, 2.0–2.9 cm, 3.0–3.9 cm and  $\geq 4$  cm) and height ( $\leq 100$  cm, 100–190 cm, 200–290 cm, 300–390 cm and  $\geq 400$  cm) classes. Statistical analyses were performed using the SPSS 15 software package (SPSS 15 for Windows, Release 2006 Chicago: SPSS Inc.).

**Table 1. Distribution, habit, conservation status and economic importance of the species represented in the study.**

| Family               | Species                     | Distribution & habitat   | Habit & status   | Uses   |
|----------------------|-----------------------------|--|--|--|
| Dipterocarpaceae     | <i>D. alatus</i> *          | Native to evergreen & dry deciduous forests of Cambodia, Laos, Myanmar, Philippines, Thailand, Vietnam, Bangladesh, Andaman islands; occurs gregariously along rivers at 0–500 m altitudes | Large tree up to 40 m tall and 150 cm in diameter; shade-tolerant and fast growing; endangered species                                       | Timber, oleoresins, medicine, soil improvement |
|                      | <i>V. cinerea</i> *         | Occurs in dry evergreen forests of Cambodia, Laos, Malaysia, Myanmar, Thailand, Vietnam  | Large tree up to 30 m & 90–100 cm in diameter; evergreen tree; shade-tolerant; endangered species  | Timber, medicine                               |
| Fabaceae/Leguminosae | <i>A. xylocarpa</i> *       | Native to Cambodia, Laos, Myanmar, Thailand, Vietnam; occurs in deciduous forests at 100–650 m altitudes   | Tree up to 30 m tall & 150 cm in diameter; light-demanding; deciduous; endangered species  | Timber, food, tanning, soil improvement        |
|                      | <i>D. cochinchinensis</i> * | Occurs in mixed deciduous forests of Cambodia, Laos, Thailand, Vietnam at altitudes of 400–500 m   | Evergreen tree up to 30 m tall, 60–80 cm in diameter; drought-tolerant but slow growing; shade-tolerant at the young age; vulnerable species | Timber, soil improvement,                      |
|                      | <i>P. macrocarpus</i>       | Native to Indochina, northern Thailand and Myanmar; introduced to India and the Caribbean  | Medium-large tree (25 m tall and 170 cm in diameter); light-demanding; deciduous, endangered species   | Timber, medicine                               |

\* IUCN World list of Threatened Trees

## Results

### Survival and growth

After seven years of planting, survival rate varied significantly among species, but not between enrichment planting methods, while root collar diameter and height varied significantly among species and between enrichment planting methods (Table 2). Significant interaction effect was observed for height. Generally survival rate was less than 55%, and the lowest survival rate was observed for *P. macrocarpus* and *A. xylocarpa* whereas the highest survival rate was recorded for *D. alatus* and *V. cinerea* (Table 3). For all species combined, seedlings planted in gaps had higher root collar diameter and height growth than those planted on lines after seven years (Table 4). Among species, root collar diameter was significantly lower for *P. macrocarpus* and *A. xylocarpa* than *D. alatus* and *V. cinerea* at all levels of enrichment planting methods (Table 4). The root collar diameter of *D. cochinchinensis* did not differ significantly from *P. macrocarpus*, *A. xylocarpa* and *D. alatus*, while it was significantly low when compared with *V. cinerea*. Height growth after seven years was the highest for *D. alatus* and *V. cinerea* compared to the other species investigated in the present study (Table 4). Particularly, height growth was favored in gaps for *V. cinerea* while that of *D. alatus* in line plantings. The rest of the species did not differ among themselves in their height growth.

**Table 2. Summary of ANOVA results for effects of species and planting methods on survival rate, root collar diameter and height after seven years of planting in mixed deciduous forests in Laos.**

| Source of variation       | d.f | Survival |         | Diameter |         | Height |         |
|---------------------------|-----|----------|---------|----------|---------|--------|---------|
|                           |     | F        | P       | F        | P       | F      | P       |
| Planting method           | 1   | 1.44     | 0.236   | 7.84     | 0.007   | 9.37   | 0.003   |
| Species                   | 4   | 12.30    | <0.0001 | 10.71    | <0.0001 | 10.89  | <0.0001 |
| Species × Planting method | 4   | 0.16     | 0.958   | 2.37     | 0.058   | 3.13   | 0.021   |
| Error                     | 60  |          |         |          |         |        |         |

**Table 3. Survival rate (Mean ± SE, %) of five tree species after seven years of planting in gaps or lines in mixed deciduous forest**

| Species (S)                      | Planting method (M)     |                         |                          |
|----------------------------------|-------------------------|-------------------------|--------------------------|
|                                  | Gap                     | Line                    | Overall mean (S)         |
| <i>Pterocarpus macrocarpus</i>   | 34.3 ± 4.3              | 28.8 ± 3.4              | 31.6 ± 2.7 <sup>a</sup>  |
| <i>Azelia xylocarpa</i>          | 36.0 ± 4.0              | 32.3 ± 4.0              | 34.2 ± 2.8 <sup>ab</sup> |
| <i>Dalbergia cochinchinensis</i> | 44.7 ± 4.2              | 41.1 ± 4.5              | 42.9 ± 3.0 <sup>b</sup>  |
| <i>Dipterocarpus alatus</i>      | 50.0 ± 1.8              | 50.1 ± 2.7              | 50.1 ± 1.6 <sup>c</sup>  |
| <i>Vatica cinerea</i>            | 52.8 ± 3.0              | 51.0 ± 3.9              | 51.9 ± 2.4 <sup>c</sup>  |
| Overall mean (M)                 | 43.6 ± 3.5 <sup>a</sup> | 40.7 ± 3.7 <sup>a</sup> |                          |

Means followed by the same letter across the column and the row are not significantly different for species (S) and planting methods (M), respectively.

**Table 4.** Root collar diameter and height (Mean  $\pm$  SE) of five tree species after seven years of planting in gaps or lines in mixed deciduous forest

| Species                          | Root collar diameter (cm)  |                            |                             |
|----------------------------------|----------------------------|----------------------------|-----------------------------|
|                                  | Gap                        | Line                       | Overall mean (S)            |
| <i>Pterocarpus macrocarpus</i>   | 1.6 $\pm$ 0.2              | 1.3 $\pm$ 0.1              | 1.5 $\pm$ 0.1 <sup>a</sup>  |
| <i>Azela xylocarpa</i>           | 1.6 $\pm$ 0.1              | 1.4 $\pm$ 0.1              | 1.5 $\pm$ 0.1 <sup>a</sup>  |
| <i>Dalbergia cochinchinensis</i> | 2.0 $\pm$ 0.1              | 1.8 $\pm$ 0.2              | 1.9 $\pm$ 0.1 <sup>ab</sup> |
| <i>Dipterocarpus alatus</i>      | 2.0 $\pm$ 0.1              | 2.2 $\pm$ 0.2              | 2.1 $\pm$ 0.1 <sup>bc</sup> |
| <i>Vatica cinerea</i>            | 2.9 $\pm$ 0.3              | 2.0 $\pm$ 0.1              | 2.4 $\pm$ 0.21 <sup>c</sup> |
| Overall mean (M)                 | 2.0 $\pm$ 0.2 <sup>a</sup> | 1.7 $\pm$ 0.1 <sup>b</sup> |                             |

| Species                          | Height (cm)                   |                               |                                |
|----------------------------------|-------------------------------|-------------------------------|--------------------------------|
|                                  | Gap                           | Line                          | Overall mean (S)               |
| <i>Pterocarpus macrocarpus</i>   | 172.4 $\pm$ 15.8              | 145.8 $\pm$ 10.9              | 159.1 $\pm$ 9.9 <sup>a</sup>   |
| <i>Azela xylocarpa</i>           | 163.3 $\pm$ 14.8              | 145.4 $\pm$ 9.4               | 154.3 $\pm$ 8.8 <sup>a</sup>   |
| <i>Dalbergia cochinchinensis</i> | 199.6 $\pm$ 7.9               | 174.6 $\pm$ 19.1              | 187.1 $\pm$ 10.5 <sup>a</sup>  |
| <i>Dipterocarpus alatus</i>      | 195.5 $\pm$ 7.6               | 202.3 $\pm$ 21.9              | 198.9 $\pm$ 11.2 <sup>ab</sup> |
| <i>Vatica cinerea</i>            | 315.0 $\pm$ 36.2              | 203.1 $\pm$ 17.0              | 259.1 $\pm$ 24.7 <sup>b</sup>  |
| Overall mean (M)                 | 209.2 $\pm$ 16.5 <sup>a</sup> | 174.3 $\pm$ 15.6 <sup>b</sup> |                                |

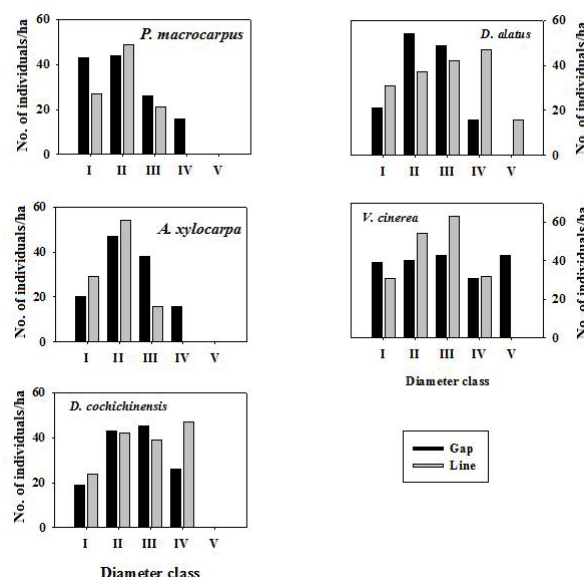
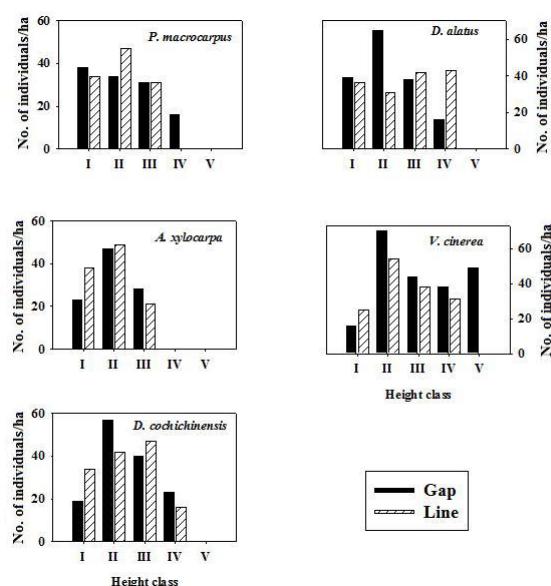
Means followed by the same letter across the column and the row are not significantly different for species (S) and planting methods (M), respectively.

#### Size class distribution

The pattern of root collar diameter distribution differed among species, with slight variation between enrichment planting methods (Fig. 2). For *P. macrocarpus*, 80% of the individuals were distributed in the first two lower diameter classes in both gaps and planting lines. Large size individuals ( $> 3$  cm) were not encountered in line plantings, but as many as 16 individuals were recorded in gaps per ha. For *A. xylocarpa*, the diameter class distribution was like a normal curve, with 57% of the individuals found in 1.0–1.9 cm class in both gaps and planting lines. Individuals of *A. xylocarpa* with root collar diameter more than 3 cm were encountered in planting gaps only. For *D. cochinchinensis*, the pattern of diameter class distribution differed between gaps and planting lines. A large number of individuals in gaps had diameters ranging from 1.0 cm to 2.9 cm while the largest number of individuals on planting lines had diameters as large as 3.0–3.9 cm, but none of the planted seedlings reached more than 4 cm diameter during seven years. The pattern of diameter class distribution for *D. alatus* was similar to that of *D. cochinchinensis* in both gaps and planting lines, except the occurrence of some individuals (16 individuals/ha) on the planting lines that have reached  $\geq 4.0$  cm in diameter. For *V. cinerea*, there was a notable difference in the pattern of diameter class distribution between gaps and planting lines. The number of individuals distributed across the diameter classes was slightly different in gaps while the largest number of individuals planted on the lines reached as big as 3 cm diameter.

The pattern of height class distribution also differed among species and between enrichment planting methods (Figure 3). A relatively large number of planted seedlings reached a height of 100–190 cm within seven years, for instance *P. macrocarpus* on planting lines, *D. alatus*, *V. cinerea* and *D. cochinchinensis* in gaps, and *A. xylocarpa* in both gaps and planting lines. For all

species, a good number of planted seedlings grew up to 300 cm in height. Notably, a good number of seedlings of *D. alatus* on planting lines and *V. cinerea* in gaps were observed in 300–390 cm and more than 400 cm height classes, respectively.

**Fig. 2** Diameter class distribution of five indigenous species used in gap and line enrichment planting (I =  $\leq 1.0$  cm, II = 1.0–1.9 cm, III = 2.0–2.9 cm, IV = 3.0–3.9 cm, V =  $\geq 4.0$  cm).**Fig. 3** Height class distribution of five indigenous species used in gap and line enrichment planting (I =  $\leq 100$  cm, II = 100–190 cm, III = 200–290 cm, IV = 300–390 cm, V =  $\geq 400$  cm).

#### Discussion

The survival rate of planted seedlings did not differ between planting gaps and lines after seven years of planting. The steadily closure of the canopy, starting the second year due to rapid growth of bamboos and the intermediate canopy trees, reduced the level

of irradiance in both gaps and planting lines. The quantity and quality of light is a key factor influencing the survival rate and growth of planted seedlings (Peña-Carlos et al. 2002; Leakey et al. 2003; Romell et al. 2008). Such low level of irradiance favored the survival of shade-tolerant species, such as *D. alatus* and *V. cinerea* while affecting the survival of light-demanding species like *P. macrocarpus*. Generally, dipterocarps germinate and become established in low irradiance under a forest canopy, albeit considerable inter-species variation in growth response to different light conditions (Tennakoon et al. 2005; Romell et al. 2008). The dipterocarp species in our study also showed differences in diameter and height growth in relation to the level of light. *V. cinerea* appeared to be less shade-tolerant than *D. alatus*, as the former species performed well in gaps that were relatively more open than the heavily shaded planting lines.

The survival rate of the studied species is comparably lower than values reported in other enrichment planting studies in the tropics (e.g. Peña-Carlos et al. 2002; Marod et al. 2004; Romell et al. 2008). Generally, the survival of planted seedlings depends on the inherent performance potential of seedlings (seedling quality) and to what extent the environmental conditions of the site allow this potential to be expressed (Folk and Grossnickle 1996). Although we do not have data on root to shoot ratio, it has been shown that favorable root to shoot dry mass ratio ( $> 1.0$  g/g) at the time of planting – an attribute, which also continued to persist in the field – enhances survival of planted seedlings (Zida et al. 2008). Seedling mortality can occur as a direct result of drought or non-drought stressors, such as herbivores, pathogens and competition exacerbated by drought.

In tropical seasonal forests, like our study site, drought is known as an important mortality factor for tree seedlings (Lieberman and Li 1992; Gerhardt 1998; Marod et al. 2004). In a watering experiment, Marod et al. (2004) have shown that drought is the apparent cause of mortality for *D. alatus* seedlings while damping off disease affected the survival of drought-adapted *P. macrocarpus* seedlings during the rainy season (Marod et al. 2002). Several studies have also shown that seedling predation is one of the apparent causes of seedling mortality. For example, Teketay (1997) suggested that defoliation by insects was one of the causes of seedling mortality in dry Afromontane forest species; Montagnini et al. (1997) observed that the periodic attack of the twig girdler *Oncideres* spp. affects the survival of *Ocotea puberula* (Nees et Mart.) Nees used in enrichment planting in Argentina; Gerhardt (1998) found that defoliation exceeding 50% combined with drought accounted for increased mortality in two Neotropical secondary forest species; Engelbrecht et al. (2005) attributed the high mortality of *Andira inermis* (W. Wright) DC in both wet and dry plots to predation by beetles; and Zida et al. (2008) ascribed the mortality of *Pterocarpus erinaceus* Poir seedlings in wet plots to herbivory by rodents, ants, and grasshoppers. We also observed predation by rodents and leaf blights on seedlings growing in both gaps and planting lines (Sovu pers. obs). As a whole, a combination of these inherent and environmental factors could be the cause of low overall survival of planted seedlings in the present study.

Once established, seedling growth was favored in gaps than in

planting lines; notably height growth, which could be related to the relatively better light condition in gaps than lines. During the inventory, we noted that the planting lines were heavily over-shadowed by the crown of the surrounding big trees and rampantly growing bamboos compared to the planting gaps. Our result is consistent with previous studies on dipterocarp seedlings that grow faster under more open canopies than closed ones (Ådjers et al. 1995; Otsamo 2000; Bebbier et al. 2002; Marod et al. 2004; Romell et al. 2008). In spite of the fact that all seedlings of each species had similar size at the time of planting, the diameter and height class distributions of individuals after seven years were irregular in both planting gaps and lines, suggesting uneven light conditions.

Maintaining an even light condition in enrichment planting of a multistory mixed forest has been a challenge (Ådjers et al. 1995; Abebe 2003). Bamboo as overstory layer could have an important effect on growth of planted seedlings. It has been shown that bamboo and liana cutting increased the solar radiation reaching the understory by 100%, and promoted sapling survival and growth rates while the increased occurrence of bamboo inhibited tree sapling abundance and richness in gaps (Campanello et al. 2007) as well as in secondary forests developed on swidden fallows (Sovu et al. 2009). In addition, young bamboos heavily compete with other trees for soil resources (Tripathi et al. 2005).

The marked variation in growth among species is associated with their ecological adaptations. The shade-tolerant dipterocarp species are acclimatized to photosynthesize more sufficiently under low irradiance level than light-demanding species (Marod et al. 2004; Romell et al. 2008). The inter-species variation in growth can also be related with their leaf phenology. While the dipterocarps are evergreen, the legumes are shedding their leaves during the dry season, thus, the latter have reduced photosynthesis efficiency although leaf shedding is an adaptation to drought in seasonally tropical dry forests. A study made in Thailand has shown that dry season watering prolonged leaf longevity, which in turn increased growth of planted *P. macrocarpus* seedlings (Marod et al. 2004). In addition, stored carbon, through accumulation during the rainy season, may affect the survival positively during the dry season for these evergreen species (Newell et al. 2002). Generally, the mean annual increment of diameter and height ranged from  $0.15\text{--}0.28\text{ cm}\cdot\text{a}^{-1}$  and  $18.44\text{--}32.72\text{ cm}\cdot\text{a}^{-1}$ , respectively; *P. macrocarpus* being the slowest and *V. cinerea* being the fastest growing species. This finding is consistent with that of Wallis (1994) who recorded comparably similar growth rate of the studied species in a plantation and, thus, classified *P. macrocarpus*, *A. xylocarpa* and *D. cochichinensis* as slow-growing and *D. alatus* and *V. cinerea* as medium-growing species.

Reliable seedling survival is a requirement for successful enrichment planting programs and efficient procedures for gap creation is an important step towards improved post-planting survival (Romell et al. 2008). Although the planting line adopted in our study had yielded good results elsewhere (Ådjers et al. 1995; Peña-Carlos et al. 2002; Abebe 2003), the degree of canopy closure was high in our cases, which, in turn, led to reduced survival and growth of light-demanding leguminous species. Simi-

larly, the planting gaps favored shade-tolerant species over light-demanding species due to low level of irradiance in the sub-canopy layer, albeit relatively being better than in planting lines. Thus, the size of planting gaps needs to be bigger than  $8 \times 8$  m employed in the present study. For example, Tuomela et al. (1996) recommended 500 m<sup>2</sup> as optimal gap size for enrichment planting of dipterocarps in logged-over rainforests. In our case, a gap size that balances the performance of both light-demanding and shade-tolerant species has to be sought for, as these species are highly esteemed for their timber values. Alternatively, the planting gaps should be tended not only by cleaning the sub-canopy vegetation but also by maintaining the canopy openness by thinning the canopy and intermediate (such as bamboo) layers periodically. Generally, a decrease in stand density to an intermediate level has been shown to enhance the growth rate of under-planted seedlings (Paquette et al. 2006). This later option may be costly though. With regard to line planting, increasing the planting width is generally believed to be accompanied by increasing seedling growth. However, the difficulty to maintain constant line width and the resulting uneven light condition coupled with the cost of annual tending operation make it less appealing. Moreover, the rigid geometric pattern of line planting makes the stands look less natural. Thus, refreshing canopy gaps and planting mixed species in gaps created during logging operations including log landings and skidding trials may compensate for high cost of initial clearing of planting lines.

## Conclusions

The results from the present enrichment planting study elucidated that gap planting favors the growth of planted seedlings over line planting, but not survival rate. This is attributed to an overall low light availability in the understory due to canopy closure, particularly rapidly in planting lines. *D. alatus* and *V. cinerea* had the best performance in terms of mean survival, diameter and height, and hence are recommended for enrichment planting under mixed deciduous forests. For *D. cochichinensis*, *P. macrocarpus* and *A. xylocarpa* with relatively low survival, increasing the gap size (400–500 m<sup>2</sup>) or line width (4–6 m) enhances light availability, which is an essential requirement for their establishment and growth. Alternatively, these leguminous species can be employed in plantations of mixed species on open sites or under canopy of young swidden forests.

## Acknowledgement

We thank the staff of the Department of Forest Management and Silviculture, Faculty of Forestry, National University of Laos for their contribution to the field work. The data collection for the present study was financed by the Swedish International Development Cooperation Agency (Sida).

## References

Abebe T. 2003. The influence of selective logging on residual stand and regeneration in a tropical rain forest in southwestern Ethiopia. PhD disser-

- tation, Swedish University of Agricultural Sciences, Umeå, Sweden. 68 p.
- Adjers G, Hadengganan S, Kuusipalo J, Nuryanto K, Vesa V. 1995. Enrichment planting of dipterocarps in logged-over secondary forests: effect of width, direction and maintenance method of planting line on selected Shorea species. *Forest Ecology and Management*, **73**: 259–270.
- Ankarfjard R, Kegl M. 1998. Tapping oleoresin from *Dipterocarpus alatus* (Dipterocarpaceae) in a Lao village. *Economic Botany*, **52**: 7–14.
- Appanah S, Weinland G. 1993. Planting quality timber trees in Peninsular Malaysia — a review. Malayan Forest Records No. 38. Forest Research Institute Malaysia, Kuala Lumpur, Malaysia.
- Ashton MS. 1995. Seedling growth of co-occurring Shorea species in the simulated light environments of a rain forest. *Forest Ecology and Management*, **72**: 1–12.
- Ashton MS, Gunatilleke CVS, Singhakumara BMP, Gunatilleke IAUN. 2001. Restoration pathways for rain forest in southwest Sri Lanka: a review of concepts and models. *Forest Ecology and Management*, **154**: 409–430.
- Bebber D, Brown N, Speight M, Moura-Costa P, Wai YS. 2002. Spatial structure of light and dipterocarp seedling growth in a tropical secondary forest. *Forest Ecology and Management*, **157**: 65–75.
- Bräutigam D. 1996. Some information and recommendations for the natural forest management and reforestation activities within the TMF of the VFC in Sangthong District. Report Lao-German Forestry Team at Ventiane Forestry College, 26 p.
- Campanello PI, Gatti MG, Ares A, Montti L, Goldsteina G. 2007. Tree regeneration and microclimate in a liana and bamboo-dominated semi deciduous Atlantic Forest. *Forest Ecology and Management*, **252**: 108–117.
- Denslow JS. 1987. Tropical rainforest gaps and tree species diversity. *Annual Review of Ecology and Systematics*, **18**: 431–451.
- Dietmar B, Christoph M, Khamla P. 2001. Forest resources development, capacity building and research: potentials and challenges illustrated by the training and model forest of the faculty of forestry in Lao P. D. R. Tropical forestry research in the new millennium: meeting demands and challenges. Proceedings of The International Conference on Forestry and Forest Products Research (CFFPR 2001) held in Kuala Lumpur, Malaysia on 1–3 October 2001, 293–307.
- Domoto K. 1997. Environmental issues in Laos: Balancing development with preservation. In: M. Than and J.L.H. Tan (eds.), *Laos' Dilemmas and Options: The challenge of Economic transition in the 1990s*, Singapore: Institute of Southeast Asian Studies, pp. 309–319.
- Engelbrecht BMJ, Kursar TA, Tyree MT. 2005. Drought effects on seedling survival in a tropical moist forest. *Trees*, **19**: 312–321.
- FOF/GTZ. 1996. Integrated forest management plan for College Intervention Area, Faculty of Forestry, Training and Model Forest, Sangthong District In, Report, p. 120.
- Folk RS, Grossnickle SC. 1996. Determining field performance potential with the use of limited environmental conditions. *New Forests*, **13**: 121–138.
- Foppes J. 1995. Farming and Forest Use Systems Survey and Recommendations for Community Forestry in the Sang Thong Training and Model Forest, Mission report commissioned by Lao-German Forestry Project, Vientiane.
- Gerhardt K. 1998. Leaf defoliation of tropical dry forest tree seedlings—implications for survival and growth. *Trees*, **13**: 88–95.
- Jacobs JW. 1996. Planning for change and sustainability in water development in Lao PDR and the Mekong River basin. *Natural Resources Forum*, **20**: 175–87.
- Jennings SB, Brown ND, Sheil D. 1999. Assessing forest canopies and understorey illumination, canopy closure, canopy cover and other measures.

- Forestry*, **72**: 59–73.
- Lamprecht H. 1990. Silviculture in the tropics: tropical forest ecosystems and their tree species; possibilities and methods for their long-term utilization. GTZ, Eschborn, 343 pp.
- Leakey ADB, Press MC, Scholes JD. 2003. Patterns of dynamic irradiance affect the photosynthetic capacity and growth of dipterocarp tree seedlings. *Oecologia*, **135**: 184–193.
- Lieberman D, Li M. 1992. Seedling recruitment pattern in a tropical dry forest in Ghana. *Journal of Vegetation Science*, **3**: 375–382.
- MAF (Ministry of Agriculture and Forestry). 1996. On Soil of Training and Model Forest of VFC, Sangthong District (1520 ha), Vientiane Municipality. Report, p. 36.
- MAF. 2005. Forestry strategy to the year 2020 of the Lao PDR. Ministry of Agriculture and Forestry, Vientiane, Lao PDR. 89 pp.
- Marod D, Kutintara U, Tanaka H, Nakashizuka T. 2004. Effects of drought and fire on seedling survival and growth under contrasting light conditions in a seasonal tropical forest. *Journal of Vegetation Science*, **15**: 691–700.
- Marod D, Kutintara U, Tanaka H, Nakashizuka T. 2002. The effects of drought and fire on seed and seedling dynamics in a tropical seasonal forest in Thailand. *Plant Ecology*, **161**: 41–57.
- Montagnini F, Eibl B, Grance L, Maiocco D, Nozzi D. 1997. Enrichment planting in over-exploited subtropical forests of the Parane region of Misiones, Argentina. *Forest Ecology and Management*, **99**: 237–246.
- Newell EA, Mulkey SS, Wright SJ. 2002. Seasonal patterns of carbohydrate storage in four tropical tree species. *Oecologia*, **131**: 333–342.
- Otsamo R. 2000. Early development of three planted indigenous tree species and natural understorey vegetation in artificial gaps in *Acacia mangium* stand on *Imperata cylindrica* grassland site in South Kalimantan, Indonesia. *New Forests*, **19**: 51–68.
- Paquette A, Bouchard A, Cogliastro A. 2006. Survival and growth of under-planted trees: a meta-analysis across four biomes. *Ecological Applications*, **16**: 1575–1589.
- Peña-Claros M, Boot RGA, Dorado-Lora J, Zonta A. 2002. Enrichment planting of *Bertholletia excelsa* in secondary forest in the Bolivian Amazon: effect of cutting line width on survival, growth and crown traits. *Forest Ecology and Management*, **161**: 159–168.
- PROFEP. 2001. Management Plan for Forest Resources Development, Training and Research 2001–2010. Project Document. Promotion of Forestry Education Project. Vientiane. 129 pp.
- Romell E, Hallsby G, Karlsson A, Garcia C. 2008. Artificial canopy gaps in a *Macaranga* spp. dominated secondary tropical rain forest—Effects on survival and above ground increment of four under-planted dipterocarp species. *Forest Ecology and Management*, **255**: 1452–1460.
- Sovu, Tigabu M, Savadogo P, Odén PC, Xayvongsa L. 2009. Recovery of secondary forests on swidden cultivation fallows in Laos. *Forest Ecology and Management*, **258**: 2666–2675.
- Teketay D. 1997. Seedling populations and regeneration of woody species in dry Afromontane forests of Ethiopia. *Forest Ecology and Management*, **98**: 149–165.
- Tennakoon MMD, Gunatilleke IAUN, Hafeel KM, Seneviratne G, Gunatilleke CVS, Ashton PMS. 2005. Ectomycorrhizal colonization and seedling growth of *Shorea* (Dipterocarpaceae) species in simulated shade environments of a Sri Lankan rain forest. *Forest Ecology and Management*, **208**: 399–405.
- Thapa GB. 1998. Issues in the Conservation and Management of Forests in Laos: The Case of Sangthong District. *Singapore Journal of Tropical Geography*, **19**: 71–91.
- Tripathi SK, Sumidab A, Shibata H, Uemurac S, Onob K., Hara T. 2005. Growth and substrate quality of fine root and soil nitrogen availability in a young *Betula ermanii* forest of northern Japan: Effects of the removal of understory dwarf bamboo (*Sasa kurilensis*). *Forest Ecology and Management*, **212**: 278–290.
- Tuomela K, Kuusipalo J, Vesa L, Nuryanto K, Sagala APS, Ådjers G. 1996. Growth of dipterocarp seedlings in artificial gaps: an experiment in a logged-over rainforest in South Kalimantan, Indonesia. *Forest Ecology and Management*, **81**: 95–100.
- Wallis P. 1994. Growth rates of planted local tree species in central Laos, Silviculture Division, Department of Forestry, Ministry of Agriculture and Forestry. Vientiane, Laos.
- Zar J. 1996. Biostatistical Analysis. Prentice-Hall Inc., New Jersey.
- Zhang H-J, Tan GT, Hoang VD, Hung NV, Cuong NM, Soejarto DD, Pezzuto JM, Fong HHS. 2003. Natural Anti-HIV Agents. Part IV. Anti-HIV Constituents from *Vatica cinerea*. *Journal of Natural Products*, **66**: 263–268.
- Zida D, Tigabu M, Sawadogo L, Odén PC. 2008. Initial seedling morphological characteristics and field performance of two Sudanian savanna species in relation to nursery production period and watering regimes. *Forest Ecology and Management*, **255**: 2151–2162.